

AN0057.1: EFM32 Series 1 LCD Driver



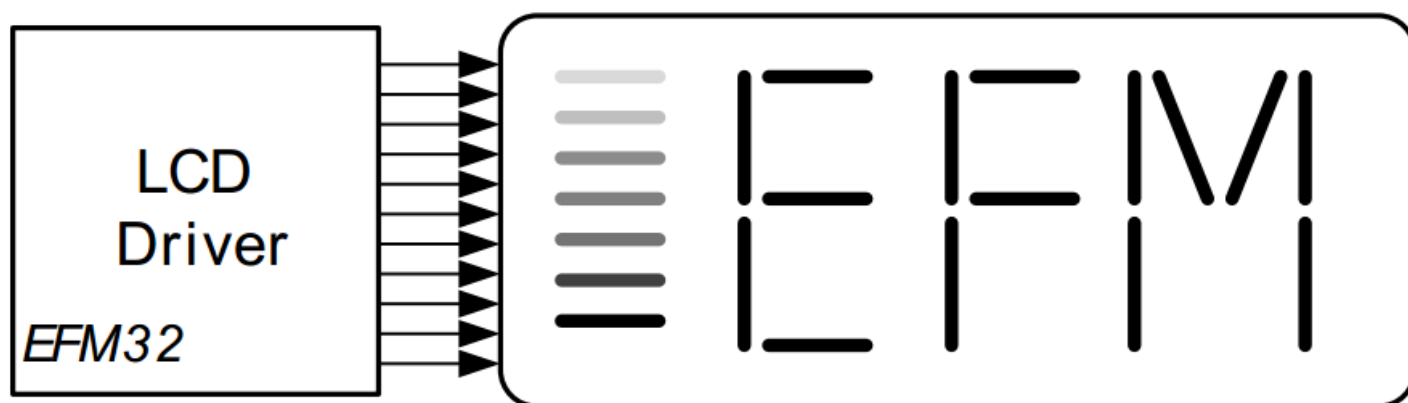
This application note provides a description of how passive segment LCD displays work and how they can be interfaced with the EFM32.

This application note includes:

- This PDF document
- Source files (zip)
 - Example C-code
 - Multiple IDE projects

KEY FEATURES

- The ultra-low power LCD driver has internal bias voltage circuit to minimize external components.
- The charge pump mode enables it to provide the LCD display up to twice the supply voltage of the device.
- The power consumption of the LCD panel itself can be lowered through the use of charge redistribution.
- The LCD driver supports autonomous animation and blinking in deep sleep without CPU intervention.



1. Device Compatibility

This application note supports multiple device families, and some functionality is different depending on the device.

EFM32 MCU Series 1 consists of:

- EFM32 Giant Gecko (EFM32GG11)
- EFM32 Tiny Gecko (EFM32TG11)

2. Introduction to LCD Segment Displays

Segmented liquid crystal displays (LCDs) are a common way to display information. The extreme low-power LCD driver in the EFM32 enables many applications to use an LCD even in energy critical systems. This document will both discuss how certain types of LCDs work, how they are driven and how to minimize their energy consumption.

2.1 Passive LCD Displays

This document will only discuss passive segment LCDs. These displays are usually constructed by sandwiching the liquid crystal between two glass plates. By using the voltage dependent, polarizing properties of the liquid crystal material, light transmission through the LCD glass can be controlled. The display is usually built up by segments that can either block light or let it pass through depending on the voltage applied over the liquid crystal within that segment.

By having a reflective coating on one side of the glass, ambient light can either be reflected back to the user or blocked by the polarizer closest to the reflective layer. This blocking of light occurs because the liquid crystal in one state will change the polarization of the light to allow it to pass both polarizers. In the other state it will not affect the polarization, and the light is then blocked because the two polarizers are orthogonally oriented with respect to each other.

This document will further use the notion that a segment is "on" when it is blocking light and "off" when light can pass through. Some displays invert this notion by letting light pass through the "on" segments, and having the "off" segments block light. The figure below illustrates how light polarization is affected when light passes through the polarizers and liquid crystal with and without an applied voltage.

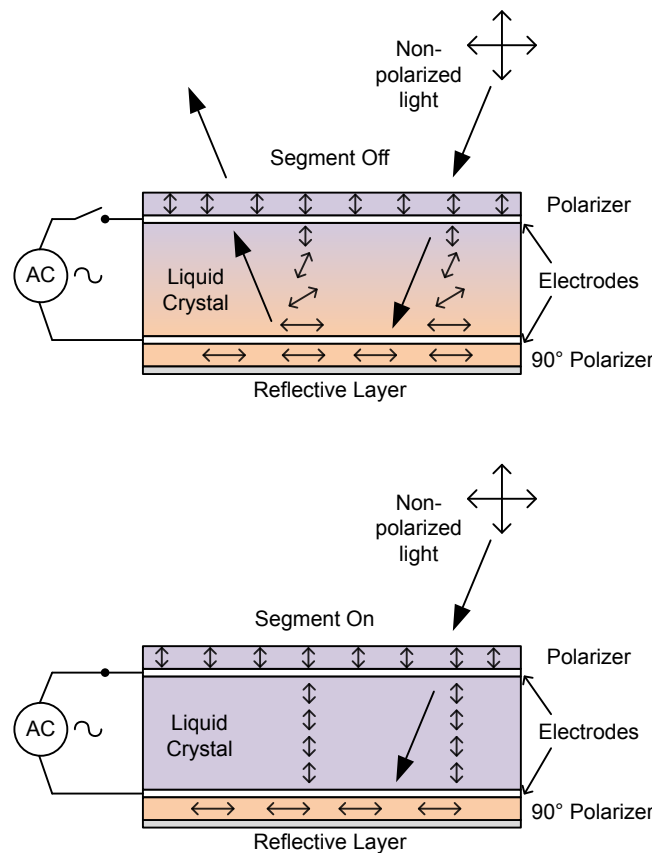


Figure 2.1. One LCD Segment with and Without Voltage Applied

When the voltage is applied, the liquid crystal does not change the polarization direction of the light. This causes it to be blocked by the second polarizer, which is oriented at an orthogonal angle to the first polarizer. If no voltage is applied, the liquid crystal will change the polarization of the light so that it can pass through both polarizers.

2.2 Driving a Display Segment

Segment LCDs do not have any internal driving circuitry. All the display pins are directly connected to each side of the corresponding segment. The simplest LCD imaginable consist of only one segment with two electrical connections, one for each side of the segment. The segment is turned on or off by applying a voltage across it. The electric field, or voltage, between the top and bottom of the liquid crystal between the glass plates directly affects the polarization properties, see [Figure 2.1 One LCD Segment with and Without Voltage Applied on page 3](#).

Just applying a constant voltage across the segment to turn it on would work, but not for a long time. The problem is that after a short time the LCD segment will be affected by the DC-current passing through it, mainly through electrolysis effects on the liquid crystal and electrodes. The solution is to drive the segment with a waveform that has an average 0 DC value. As long as the voltage is switched fast enough (30 - 100 Hz), it will be the RMS value of the voltage that affects the amount of polarization.

The simplest way to drive a "one segment" LCD with the correct zero DC bias would be to apply two identical and optionally phase shifted, square waveforms. By shifting the phase of one signal with respect to the other by 180 degrees, the apparent RMS voltage across the segment goes from 0 to two times the voltage of the two waveforms. See the following figure.

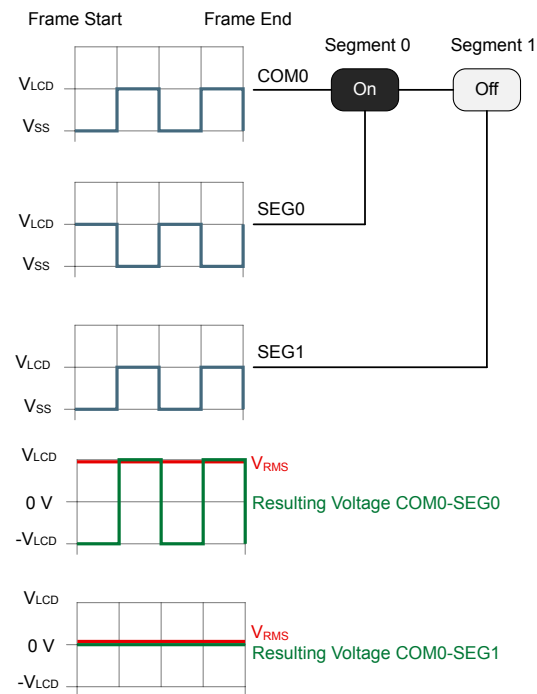


Figure 2.2. Static Driving of Two LCD Segments, One On and One Off

The reason for using two square waveforms, offset from 0 V is that this is simpler to achieve on a microcontroller with a single power supply. Negative voltages are rarely available, so connecting one side of the LCD segments to ground is not an option.

2.2.1 Driving Many Segments: Static Driving

An LCD display most often has more than one segment. Usually the segments are connected with one side common to many of the other segments, this is called the "common"-electrode. The other side of the segment has its own pin connection, the "segment"-electrode. See the following figure.

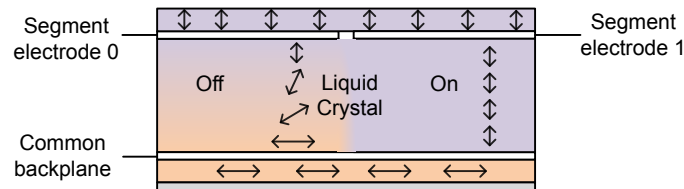


Figure 2.3. Common Backplane with Two Segments, One On and One Off

With a statically driven LCD display, there is only one common electrode and each segment has its own segment electrode. Both the common electrode and segments are driven with a square wave form. Segments that are "on" are driven with a phase shifted waveform to make the RMS voltage across these segment non-zero. See [Figure 2.2 Static Driving of Two LCD Segments, One On and One Off on page 4](#).

2.2.2 Driving Many Segments: Multiplexed Driving

With the static driving approach with one segment line for each segment, large displays with many segments would need a large number of the microcontroller pins just to drive the display. By multiplexing several common and segment lines, fewer pins can be used to drive more segments. The total number of segments that can be driven is the product of the number of common lines and segment lines. Usually maximum contrast goes down and current consumption goes up with a higher number of common lines.

It is the amplitude of the apparent RMS voltage across a segment that determines if it is on or off. A segment with a low RMS voltage applied will seem to be off even if the voltage is non-zero. The relationship between apparent RMS voltage across a segment and its visual properties is non-linear. This non-linearity is utilized when multiplexing several segments on the same driving pins. A segment does not need to see zero RMS voltage to be perceived as completely off by the user.

Each common line and segment line is driven with waveforms consisting of more than two voltage levels as in the static driving case. The number of voltage levels are known as "bias" levels. By carefully selecting the waveform of each segment line and common line, it is possible to make some segments "see" a low RMS voltage, while others "see" a high RMS voltage, even if the segments share either their common or segment electrode with other segments. See the figure below.

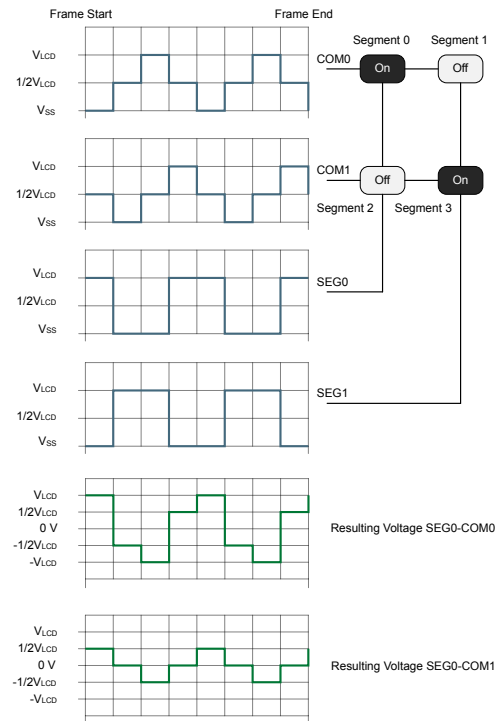


Figure 2.4. Multiplexed Driving of Four LCD Segments

In the figure above there are two segment lines and two common lines. The bias is 1/2, which means there are 3 different voltage levels possible. The combination of the waveform on COM0 and SEG0 makes the segment between SEG0 and COM0 turn on, while the segment between SEG0 and COM1 is off. Notice the difference in RMS voltage across the two segments.

For a multiplexed display, the difference in RMS voltage between segments that are on and off will be smaller than for a statically driven display. This means that the visual quality and appearance, such as contrast and viewing angle, must be more carefully calibrated for a multiplexed display. The contrast can be calibrated in software by adjusting the bias voltage levels within the LCD driver. Viewing angle and appearance under different lighting conditions should be considered when selecting the actual display.

3. EFM32 LCD Driver

This chapter explains some of the features and possibilities of the EFM32 built-in LCD driving peripheral. For a full set of features and limitations, please see the reference manual for the specific device family.

3.1 Multiplexing

The EFM32 LCD driver can multiplex up to 8 common lines, of which 4 are dedicated common lines and 4 are part of the segment lines (not available on all parts). The multiplexing waveforms and bias voltage levels are automatically handled within the LCD driver peripheral. The software only needs to set segments on or off and adjust contrast if necessary.

If multiplexing is not needed, static driving of the display is also possible. A statically-driven display can have higher contrast than a multiplexed display. A static display with only one common line is usually lower power than a multiplexed display, and, in most cases, current consumption goes up with a larger number of common lines.

3.2 Waveform and Bias Selection

When selecting multiplex mode and number of bias levels according to how many common lines the LCD has, the waveforms are selected automatically by the EFM32 LCD peripheral. Normal and low power waveform modes are selectable with the difference being that the low power mode achieves zero DC bias over several frames. In other words, the DC bias across LCD segments is not zero within a frame. This is not a problem for most displays and applications and is the mode almost always recommended.

Figure 3.1 Normal and Low Power Waveform, Only Common Signal Shown on page 7 shows the difference between low power and normal mode and its larger number of waveform changes within a frame. If flickering or contrast problems occur are observed in low-power mode, normal mode can be selected instead. An illustration of the different waveforms used, up to and including quadplexed mode, can be found in the reference manual.

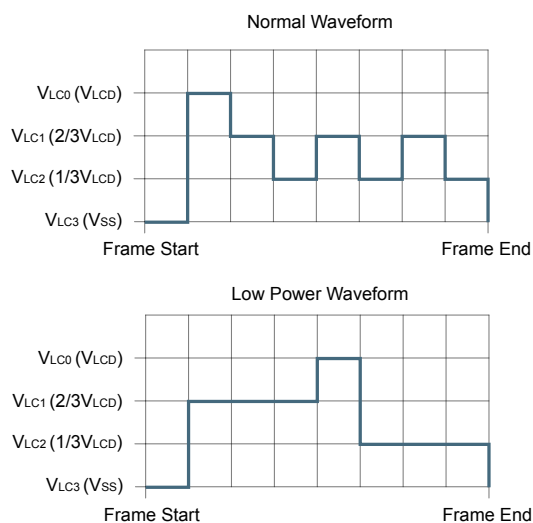


Figure 3.1. Normal and Low Power Waveform, Only Common Signal Shown

Selecting the correct bias is necessary to provide the waveform generator with enough voltage levels to produce the necessary waveform for the chosen number of common lines. In general 5- to 8-plexed modes need 1/4 bias (5 voltage levels), 3- to 4-plexed modes need 1/3 bias (4 voltage levels), while 2-plexed mode needs 1/2 bias (3 voltage levels) and static mode needs only 2 voltage levels.

The following table illustrates the need for more bias levels when increasing the number of multiplexed common lines. The difference between V_{on} and V_{off} is essentially a measurement of the possible contrast. Notice that for the static driven display, the contrast is essentially infinite. Refer to [Figure 3.2 Relative Transmission of Light Through the LCD for Changes in the Applied RMS Voltage on page 9](#) for an illustration of the non-linear properties of the liquid crystal and why the difference between V_{on} and V_{off} is a measure of contrast.

Table 3.1. LCD Drive Modes, Bias Setting and Contrast Characteristics

LCD drive mode configuration	LCD bias setting	Contrast = $V_{on(RMS)}/V_{off(RMS)}$
Static	Static	Infinite
1:2 multiplex	1/2	2.24
1:2 multiplex	1/3	2.24
1:2 multiplex	1/4	1.85
1:4 multiplex	1/2	1.53
1:4 multiplex	1/3	1.73
1:4 multiplex	1/4	1.65
1:6 multiplex	1/2	1.34
1:6 multiplex	1/3	1.53
1:6 multiplex	1/4	1.53
1:8 multiplex	1/2	1.25
1:8 multiplex	1/3	1.41
1:8 multiplex	1/4	1.45

Note that for some multiplex configurations, contrast actually goes down with an increased number of bias levels. In general a higher number of bias levels also means higher energy consumption, so for a given number of multiplexed common lines, the lowest possible number of bias levels should be chosen. Depending on the LCD, contrast might be acceptable even with a lower number of bias levels.

3.3 Contrast

Adjusting the contrast of the LCD is only relevant to multiplexed displays because the off segments in multiplexed mode still have a non-zero RMS voltage across them. The purpose of contrast adjustment is to get the RMS voltage of off segments below a certain threshold so these segments are perceived as off but there is still a high enough voltage across the on segments for them to be perceived as on. Contrast varies among LCDs and also changes with temperature and voltage, thus making adjustments necessary. See [Figure 3.2 Relative Transmission of Light Through the LCD for Changes in the Applied RMS Voltage on page 9](#) for an illustration of the non-linear nature of the liquid crystal material with respect to applied voltage and transmission of light without changing polarization.

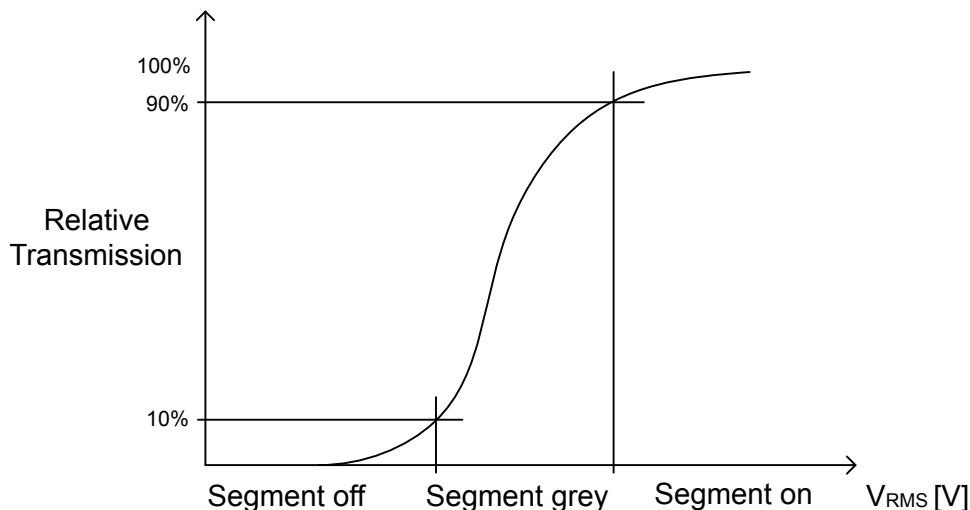


Figure 3.2. Relative Transmission of Light Through the LCD for Changes in the Applied RMS Voltage

3.3.1 Charge Pump Mode

Some LCDs require higher voltage waveforms to work. The EFM32 Series 1 LCD peripheral supports charge pump mode to generate a V_{LCD} voltage up to twice the supply voltage of the device. V_{LCD} is adjusted by the LCD_DISPCTRL register CONTRAST[5:0] field.

The usual sign that charge pump mode is needed is that LCD contrast goes down and on segments appear dim even with the contrast adjusted to its highest level in other modes. Reduced contrast and even perceived blanking of the display is also a problem at low temperatures and can be resolved in software by enabling charge pump mode to drive V_{LCD} at a higher voltage level.

See the reference manual for more information on the external components necessary for using the charge pump and how to enable and adjust its output voltage.

3.3.2 Contrast Compensation

As mentioned earlier, LCD contrast is affected by both the EFM32 supply voltage and the temperature of the LCD glass. If the system is intended for operation over a wide range of supply voltages and temperatures, the contrast, and optionally the use of charge pump mode, should be adjusted under software control at predetermined thresholds.

The correct contrast adjustment varies between different displays and viewing angles. Exactly at which voltages and temperatures the charge pump mode is needed is also dependent on the LCD display itself. Some information can often be found in the LCD glass documentation.

3.4 Animation and Blinking

The EFM32 LCD driver includes special features to enable animation and blinking of specific segments without any software intervention. This is useful for displaying continuous animation to signal that a device is alive, without the need to wake up from deep sleep to update the segments.

The animation feature is available on segments 0 to 7 (or segments 8 to 15) multiplexed with LCD_COM0. The animation is implemented as two programmable 8-bit registers that are shifted left or right every other Animation state for a total of 16 states. The animation state changes with each frame counter event. See the reference manual for more information on the animation feature and its interface. The animation registers and shift operation are shown in the following image.

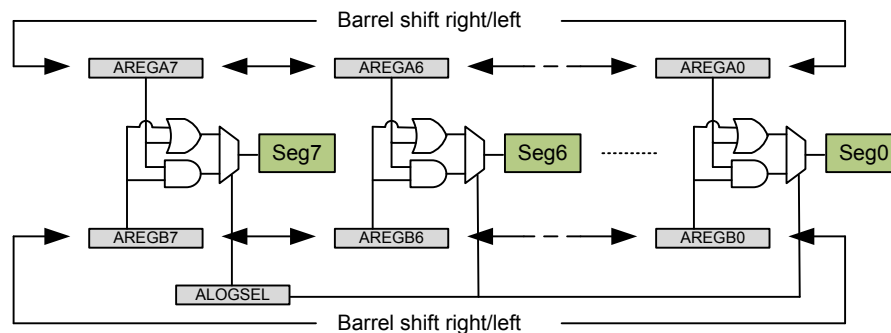


Figure 3.3. Animation Function with Barrel Shift and Logic Operations

The included software example demonstrates how to enable and configure the blinking and animation features.

3.5 LCD Interrupts

The LCD peripheral contains one interrupt source, the frame counter interrupt. It can be used to time and execute display updates, animation changes or similar display effects. Since there are no limitations on when the LCD segment registers can be updated, there is no need to use the frame counter interrupt to time segment updates. The driver supplied in the Gecko SDK Suite and which is used in the software example with this application note does not use this interrupt. See the reference manual for more information.

3.6 Minimize Energy Consumption

The LCD driver is itself a very low power peripheral that can operate in deep sleep mode (EM2) from a low frequency oscillator. When connecting a display to the EFM32, the capacitive load presented by the LCD results in increased energy consumption. This can be minimized by optimizing a few parameters.

After the multiplex and bias settings are configured correctly, and low power waveform is selected, the display refresh rate should be configured to the lowest possible value that does not cause flickering by setting the frame rate division and prescale values.

Charge pump mode should not be used unless absolutely necessary. Instead, contrast should first be adjusted to counteract lower supply voltage or temperatures. Remember that charge pump mode significantly increases current consumption.

In addition, the power consumption of the LCD panel itself can be lowered through the use of charge redistribution. When charge redistribution is in use, all segments are briefly shorted together, allowing low segments to be partially charged by the energy in high segments instead of using additional energy from the power supply. With charge redistribution, the EFM32 LCD peripheral can reduce current consumption by 10% to 24% in the low power waveform mode and by up to 40% in the normal waveform mode. The included software example demonstrates charge redistribution and shows the reduction in current draw when it is enabled.

CHGRDST[1:0] in LCD_DISPCTRL sets the charge redistribution duty cycle, which should be 5% or less to prevent any reduction in LCD pin RMS voltage. See the reference manual for how to calculate and set charge redistribution duty cycle.

If charge redistribution is not used, a larger CMU prescaling value is recommended to minimize power consumed by the LCD block itself. Note that disabling charge redistribution will always result in higher system power consumption. Charge redistribution is on by default, but it can be disabled by setting CHGRDST to 0 in LCD_DISPCTRL register.

4. Software Examples

This application note includes a simple “Hello World” example that demonstrates use of the LCD peripheral with the Gecko SDK Suite display drivers, including advanced features such as animation and the charge redistribution feature.

Note that a software example is not included for the EFM32 Series 1 Giant Gecko family because its Starter Kit (STK) does not have a liquid crystal display. The LCD peripheral does, however, have the same features, apart from segment count, so porting the example to a custom board would be trivial.

4.1 Hello World

This example uses the BSP (Board Support Package) drivers to enable and write a message on the LCD panel. It configures the LCD peripheral correctly for low current consumption without flickering. In addition, it uses the animation feature of the LCD peripheral to show a revolving door while the device remains in deep sleep.

Furthermore, the example code demonstrates the benefits of charge redistribution in the low power and normal waveform modes. Use PB1 on the STK to select one of the four configurations shown below, then press PB0 to run the demo. All segments are enabled in the selected mode, and the processor enters EM2 and remains there, permitting measurement current draw, until the RESET button is pressed. The average current consumption measured by Simplicity Studio's Energy Profiler and the calculated reduction in current draw are listed in the following table.

- Normal waveform mode and turn off charge redistribution
- Normal waveform mode and turn on charge redistribution
- Low power waveform mode and turn off charge redistribution
- Low power waveform mode and turn on charge redistribution

Table 4.1. Current Consumption Reduction with and without Charge Redistribution

		Full display, all segments enabled Frame Rate = 32Hz CHGRDST percent = 1/64 => 1.6%		
Mode	LCD Peripheral Configuration	Measured	LCD Only	Reduction
CHRGDST1	Normal Waveform, Redistribution Disable	13.29 μ A	10.47 μ A	35.15%
CHRGDST2	Normal Waveform, Redistribution Enable	9.61 μ A	6.79 μ A	
CHRGDST3	Low Power Waveform, Redistribution Disable	7.53 μ A	4.71 μ A	15.29%
CHRGDST4	Low Power Waveform, Redistribution Enable	6.81 μ A	3.99 μ A	

The reduction in current consumption after enabling charge redistribution is calculated here by subtracting the consumption of the CPU and other peripherals (2.82 μ A) from the measured result.

Increasing the charge redistribution duty cycle can reduce current draw further; however, the redistribution time should be no more than 5% to avoid a drop in LCD pin RMS voltage.

4.2 Porting the LCD Driver to other Displays

This section contains a description of the necessary steps needed to port the BSP LCD driver to other displays with different segment and common line mapping. Only 4-plexed and 8-plexed displays are covered because these are the only types of displays used by EFM32 kits. That being said, it should be fairly easy to port the driver to other multiplexed configurations after understanding how to port the display driver in general.

A segment LCD most often consists of up to three types of "information displaying modules:"

- Individual symbol segments that can be turned on/off. These can be anything from a low battery symbol to Celsius/Fahrenheit temperature indication. The EFM32 STK LCD glass contains several unique symbols. Check the schematics for the kit board to see available symbol segments.
- 7 Segment numbers. Each digit is built from 7 segments that can be turned on or off to display the numbers from 0 to 9. The EFM32 STK LCD glass contains some of these in the top right corner.

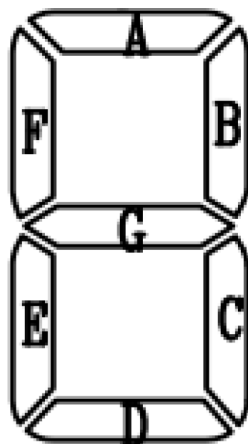


Figure 4.1. Seven Segment Digit with Typical Naming of Segments

- 14 Segment alphanumeric letters, sometimes referred to as a "star burst" or "union jack" display. Each letter or digit is built from 14 segments that can be turned on or off to display any number from 0 to 9 or any uppercase or lowercase letter from A to Z. The EFM32 STK LCD glass contains some of these in the lower part of the display.

Note that the BSP driver only supports mapping for 14-segment star burst letters. Some LCDs have 15 or 16 segment letters, such that the mapping of letters to segments must also be changed in addition to the mapping of segments to pins.

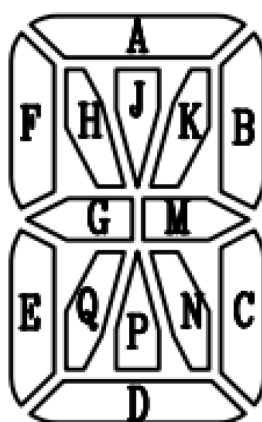


Figure 4.2. Fourteen Segment Alphanumeric Letter with Typical Naming of Segments

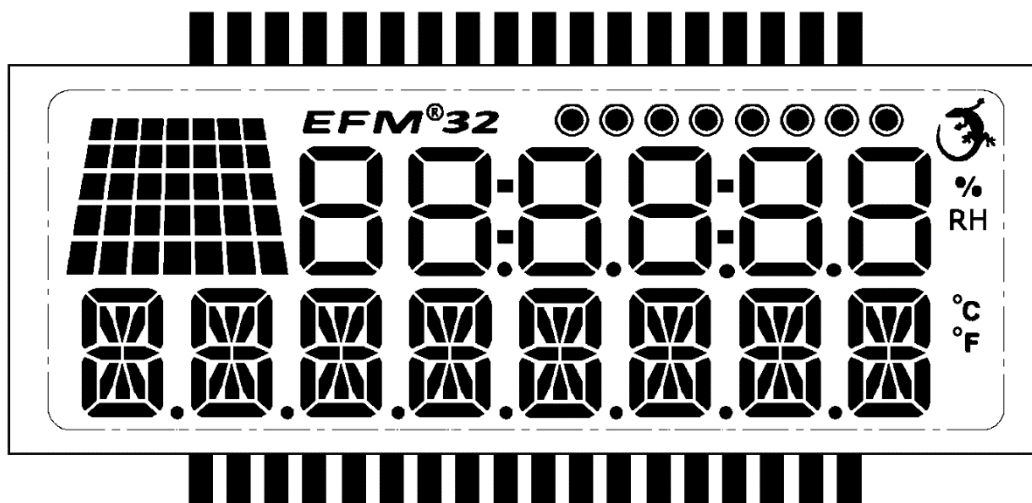


Figure 4.3. EFM32 Kit LCD Glass Segments

Figure 4.3 EFM32 Kit LCD Glass Segments on page 13 illustrates how the EFM32 STK LCD glass is built up. Notice the three types of segment constellations: symbols, 7-segment digits, and 14-segment alphanumeric. The three types of constellations are handled separately in the board support package LCD driver.

4.2.1 Understanding the LCD Segment Map

All the mapping information on which segment and common line is connected to which LCD segment is contained in the *segmentlcdconfig.h* file which varies between the different starter kits and development kits. It is contained in the "config" folder within each kit software example folder.

To understand how *segmentlcdconfig.h* is built up, it helps to look at the LCD display mapping figure which is located in the kit schematic document and at the same time have the *segmentlcdconfig.h* file open. For better understanding of this section, the reader is encouraged to do this.

As an example, consider the first alphanumeric letter in the "EFM_DISPLAY_DEF" #define in *segmentlcdconfig.h* for the SLSTK3301A. ".com[0]" and ".bit[0]" refers to the common and segment line of the first segment (denoted A in the 14-segment letter in Figure 4.2 Fourteen Segment Alphanumeric Letter with Typical Naming of Segments on page 12). ".com[1]" and ".bit[1]" refers to the second segment (denoted B in the 14-segment letter in Figure 4.2 Fourteen Segment Alphanumeric Letter with Typical Naming of Segments on page 12) and so on.

Note that in Figure 4.4 EFM32 LCD Segment to Pin Assignment on page 14, the PIN number and COMn refer to the pins of the LCD panel and not the LCD peripheral on the EFM32. For example, "COM0" is the COM0 pin of the LCD panel, but it is connected to the LCD_COM3 pin of the EFM32 LCD peripheral in the schematic.

For the first alphanumeric letter in the *segmentlcdconfig.h* file, the ".com[0] = 4" and ".bit[0] = 19" mapping refer to common line 4 and segment 19 of the EFM32 LCD peripheral which correspond to COM4 and PIN 1 in the LCD glass figure (Figure 4.4 EFM32 LCD Segment to Pin Assignment on page 14). Check the schematic document for the connection between LCD display and LCD driver peripheral.

4.2.2 Porting the LCD Segment Map

This section is an actual step by step description of the porting. Start with selecting a kit with the same number of multiplexed common lines as your display. Either select the SLSTK3301A or SLSTK3701A.

Open the *segmentlcdconfig.h* file for the selected kit. Start with the easiest part, the individual symbol segments, if any. These have their individual segment and common line #defines at the start of the file. Change a couple of them and check if it is correct by turning on only those segments. Watch the LCD glass and check if the mapping is correct. This should indicate if the common lines/segment lines are connected in the expected order. Common problems include reversal of the common and segment lines, errors in the LCD module documentation, and PCB schematic or layout errors.

Next on the list are the 7-segment digits, if any. These are a bit easier than the 14-segment alphanumeric because they contain fewer segments per digit. Remember that ".com[0]" and ".bit[0]" refer the common and segment line of the first segment (segment A) in the digit, ".com[1]" and ".bit[1]" to segment B, and so on. These are most often named A-G in alphabetic order, clockwise around the 7-segment digit, starting at the top, as shown in [Figure 4.1 Seven Segment Digit with Typical Naming of Segments on page 12](#).

If the display contains "star burst" letters (14-segment letters), these can be ported in the same way as the 7-segment digits. The numbering is also here usually clockwise, starting from the top. Note that the actual letters selected by the LCD glass manufacturer to represent each segment can vary quite a bit. In any case, the LCD glass on the EFM32 Starter Kits combined with the *segmentlcdconfig.h* supplied for this display should make it possible to figure out the correct numbering of the segments. See [Figure 4.4 EFM32 LCD Segment to Pin Assignment on page 14](#) for the mapping and naming of all the segments in the 8-plexed STK LCD glass.

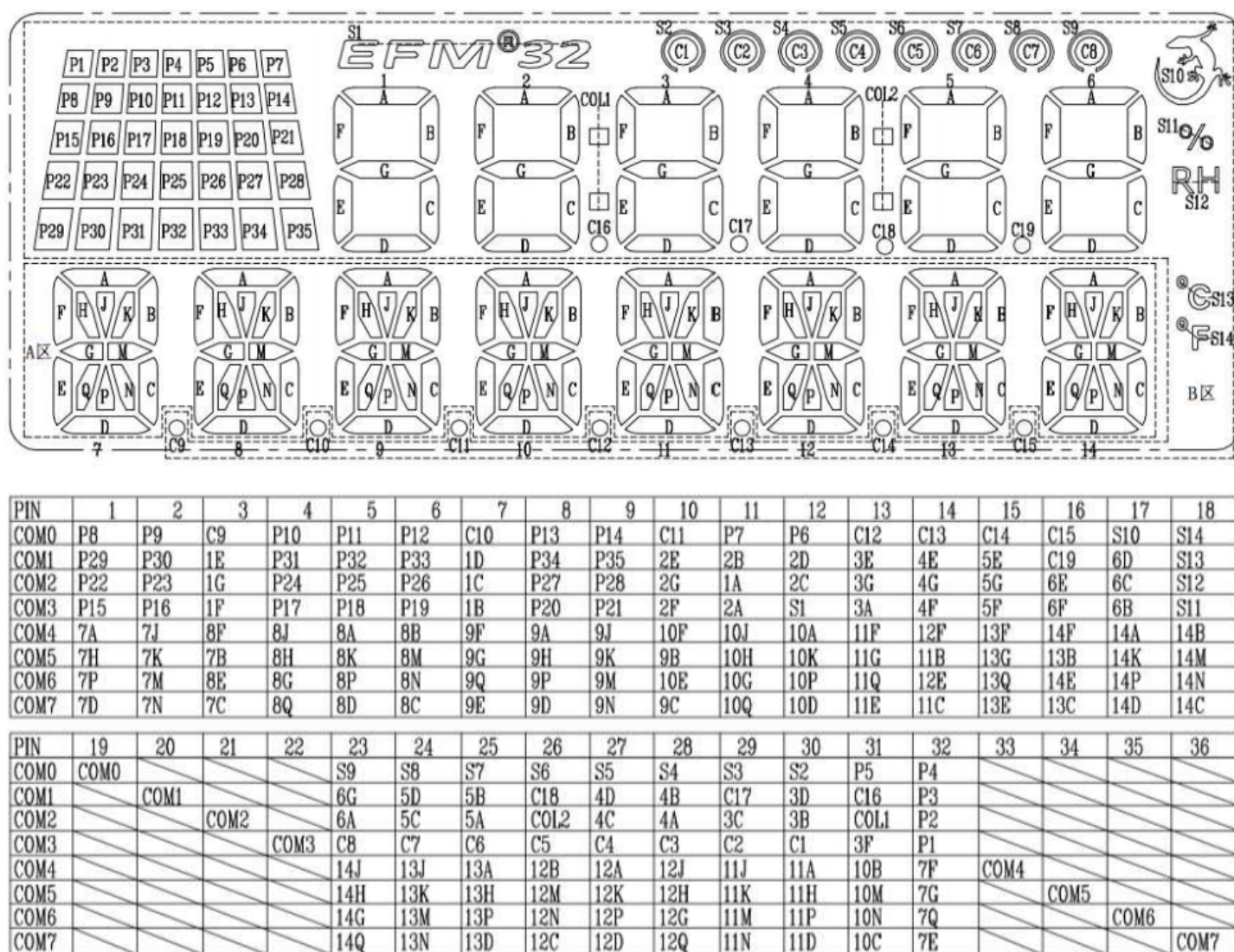


Figure 4.4. EFM32 LCD Segment to Pin Assignment

5. Revision History

Revision 1.05

May 2020

- Replaced " V_{RMS} " text to "Voltage" in [Figure 2.2 Static Driving of Two LCD Segments, One On and One Off on page 4](#) and added V_{RMS} waveforms.
- Replaced " V_{RMS} " text to "Voltage" in [Figure 2.4 Multiplexed Driving of Four LCD Segments on page 6](#).

Revision 1.04

February 2018

- Split AN0057 into AN0057.0 and AN0057.1 for MCU Series 0 and MCU Series 1 devices, respectively.
- Added the 1. Device Compatibility section.
- Added support for EFM32 Series 1 device EFM32TG11.
- Re-organized the example code structure.

Revision 1.03

October 2013

New cover layout

Revision 1.02

May 2013

Added software projects for ARM-GCC and Atollic TrueStudio.

Revision 1.01

February 2013

Fixed linker error for DK3550 project.

Revision 1.00

February 2013

Initial revision.

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